quadrants. And this expression, although containing only three constants, fitted with considerable accuracy all the curves given in the several sheets accompanying the paper.

The results of the investigation, briefly summed up, are as follows:—

1. The quadrant electrometer as made by Messrs. White, although it may be carefully adjusted for symmetry, does not usually even approximately obey the recognised law for a quadrant electrometer when the potential of the needle is altered.

2. The peculiarities in the behaviour of the White electrometer are due mainly to the electrical action between the guard tube and the needle, and to the slight tilting of the needle that occurs at high potentials.

3. By special adjustments of the quadrants of the White electrometer the sensibility can be made to be either nearly independent of the potential of the needle, or to be directly proportional to the potential, or to increase more rapidly than the potential of the needle.

4. By altering the construction of the instrument as described, the conventional law for the quadrant electrometer is obtained without any special adjustment of the quadrants beyond that for symmetry, and the instrument is rendered many times as sensitive as the specimen we possess of the White pattern.

V. "Researches on the Absorption of Oxygen and Formation of Carbonic Acid in ordinary Human Respiration, and in the Respiration of Air containing an Excess of Carbonic Acid." By WILLIAM MARCET, M.D., F.R.S. Received May 25, 1891.

Allow me to begin by recording the valuable help I have experienced throughout the present enquiry from my assistant, Mr. Edward Russell, F.C.S. We have both put our shoulders to the wheel, and have gone together through the great number of calculations the work entailed. I am much indebted to Mr. Russell for the pains he has taken, and the accuracy of his judgment whenever a knotty point had to be met and overcome.

My object in the following paper is to give an account of the consumption of oxygen in human respiration, or, in other words, to determine the proportions of oxygen transformed into carbonic acid, and of oxygen retained in the blood, to which is added a short inquiry into the effects produced by the inhalation of air containing CO_2 on the interchange of the pulmonary gases. The investigation was carried out, so far, on myself and Mr. Russell, while under the

influence of food and when fasting, or at a period of four hours at least from breakfast, when a desire for lunch was clearly felt.

The results aimed at, although applying to man instead of animals, were similar in kind to those obtained on animals by Messrs. Regnault and Reiset,* and more recently by Messrs. Chapman and Brubacker, of Philadelphia.† Regnault and Reiset by their admirable researches have paved the way to a correct history of the chemical phenomena of respiration; and Chapman and Brubacker, who have repeated these experiments by a similar method, deserve much praise for their laborious and interesting investigation, confirming, in a marked degree, the results obtained by Regnault and Reiset.

Rabbits being the subject of the experiments, Regnault and Reiset obtained for the relation between the oxygen consumed and CO_2 produced a mean figure of 0·919 from six experiments; with Messrs. Chapman and Brubacker the corresponding result, also from rabbits, was 0·90.

These experiments were made by confining animals in a receiver or bell-jar, and absorbing the CO_2 they produced with potassium hydrate aided by mechanical means, while oxygen was supplied automatically as fast as the CO_2 was absorbed, and as nearly as possible in equal volumes. An examination of the figures expressing the results obtained by Regnault and Reiset and the American physiologists will show that the animals at the end of the experiment had to breathe an atmosphere containing an excess of CO_2, as it was impossible to rid the air entirely of this gas. The proportion of CO_2 present in the air at the close of the experiment occasionally rose to 3 per cent. and higher, and this is a rather large contamination to allow of results being applied to natural breathing, considering that atmospheric air contains only from 0·04 to 0·1 per cent. CO_2.

Moreover, the proportions of oxygen in the chamber at the end of the experiments varied considerably, although always lower than the corresponding proportion in atmospheric air. So that, towards the end of the experiments, the animals were breathing air containing an excess of CO_2 and a deficiency of O.

There must be another difficulty to contend with in such kinds of experiments, amounting to the impossibility of keeping the animals quiet, and muscular action exerts, we know, a very positive influence on the phenomena of respiration.

In addition to the labours of Regnault and Reiset, and Chapman and Brubacker, I have to quote the papers of Carl Speck,‡ and of

* 'Annales de Chimie et de Physique,' 1849.

† 'Proceedings of the Academy of Natural Sciences of Philadelphia,' January, 1891.

‡ "Experimentelle Untersuchungen über den Einfluss der Nahrung auf Sauerstoffverbrauch und Kohlensäureausscheidung des Menschen," von Carl Speck, 'Archiv für Pathologie,' 1874.

Messrs. Jolyet, C. T. Bergonié, and Sigalas,* while an elaborate paper has appeared last month (April) in the 'Annales de Chimie et de Physique,'' by Messrs. Hanriot and Ch. Richet, which also treats of the interchange of the respiratory gases in man. In the experiments last mentioned, the air inspired was breathed through a gas meter, and then expired through another meter. Next, the air expired was conducted through an apparatus destined to the absorption of the CO_2, and finally through a third meter. The meter on the inspiratory track showed the volume of air inspired, the first expiratory meter registered the volume of air expired, and the second the volume of CO_2 produced, which was equal to the difference of volumes as indicated by the two meters. The difference of volume registered by the inspiratory and first expiratory meters yielded the volume of oxygen absorbed.

The method is ingenious; at first sight it appears satisfactory, but on looking into the process with an experience acquired from about 15 years' work, on and off, on the chemical phenomena of respiration, and with the knowledge of the difficulties concerning the volumetric determination of carbonic acid, I cannot help considering the method too rough for an inquiry which requires extremely delicate manipulation.

I must also take exception to the use of the face-pieces and valves which were introduced in these experiments, though reluctantly, as the authors remark. In my earliest inquiries on the chemical phenomena of respiration, face-pieces and valves were employed; but eventually I gave them up from their interfering with free respiration, and from the difficulty of maintaining the valves in an absolutely reliable state.

Method of Investigation and Instruments.

The method of investigation adopted in the present researches is quite different from any of those made use of by other authors. Every care was taken to breathe naturally during the experiment. The recumbent position was assumed in a deck chair, with the body perfectly supported, and the person under experiment inspired through the nose and expired through the mouth, compressing his nostrils, during expiration, if it was thought necessary, with a slight motion of the hand, or of the index fingers of both hands. The movement was, indeed, hardly perceptible, and could not, by any means, influence the CO_2 expired. After a sufficient period of rest had been allowed, the expired air was collected in a receiver or bell-jar suspended over salt-water, which has been described on former occasions. The re-

* "Échanges gazeux pulmonaires dans la respiration de l'homme," 'Comptes Rendus,' 1887.

ceiver was so carefully counterpoised that the person under experiment could not tell whether he was breathing into it or into the external air. It was supplied with a scale divided into litres and fractions of litres; an oil gauge showed the pressure of the air within it, and a thermometer its temperature. A number of precautions were taken in connexion with the mode of collecting the air expired, which cannot be entered into at present. I have satisfied myself that breathing into these bell-jars is identical with natural respiration: the volumes expired, say, per minute really corresponding with the volume of air expired per minute while breathing naturally into the open air. Each experiment lasted between 7 and 8 minutes.

The determination of carbonic acid in the air expired was made exactly in the way described in a previous paper to the Royal Society.* The air expired was transferred from the bell-jar to a cylinder, shaken with baryta-water, and finally determined by titration, according to Pettenkofer's method.

The oxygen was determined in a eudiometer, constructed on the same principle as the eudiometer I have described in the 'Proceedings of the Royal Society,'† but modified and improved. Instead of a straight tube this instrument consists of a U-tube, with a neck and a glass stop-cock at its bend. One limb is left open, and the other is closed at the top by an iron cap, in which a three-way cock is fitted, perfectly air-tight. Two short iron tubes project beyond the tap. Both limbs of the U-tube are graduated. The limb bearing the iron cap is graduated into cubic centimetres, and the open limb is graduated into divisions corresponding exactly with those on the other limb, so that, whatever be the level of the mercury in the U-tube under atmospheric pressure, the readings are identical in both limbs. The scale at the back of the open limb is movable, so that it can be brought easily into its proper position and fixed there. The closed limb is surrounded with a water jacket, and the iron cap is partly immersed in water, while the platinum wires are embedded in a shellac cement, so as to be effectually protected from contact with the water.

The hydrogen for exploding the gas was prepared with every care from zinc and sulphuric acid; it was washed first through a strong solution of potassium hydrate, and then through water. A volume of hydrogen, at least nine or ten times that of the air-spaces in the Woulffe's bottles, was passed through before collecting the gas; it was finally aspired into a glass bell-jar of a capacity of about a litre, and movable up and down in a glass receiver holding water.

* "A Chemical Enquiry into the Phenomena of Human Respiration," 'Phil. Trans.,' B, 1890.

† "A new form of Eudiometer," 'Roy. Soc. Proc.,' June, 1888.

Before the hydrogen was used it was tested in nearly every case with atmospheric air.

The determinations of oxygen were made as follows:—The U-tube was first of all filled to overflowing with mercury through its open limb, the three-way cock being turned so as to let out the mercury after filling the tube; by this means every trace of gas was driven out of the tube.

Then the stop-cock was turned so as to close the eudiometer and let the hydrogen gas through it, and the instrument having been brought into connexion with the gas-holder by india-rubber tubing, the hydrogen, under a pressure of an inch or more of water, was driven rapidly through the stop-cock, being, moreover, aspired by the dilatation of an india-rubber syringe. The cock was now turned so as to admit the hydrogen into the eudiometer, and the mercury, being let out at the bend of the U-tube, aspired the required volume of hydrogen into the instrument; this amounted to from 18 to 20 c.c. The bell-jar was then placed under atmospheric pressure, the gas turned off, and the height of the mercury if not exactly the same in both limbs was adjusted by adding or withdrawing mercury until the readings were alike.

The air to be analysed for the determination of oxygen had been collected by displacement with water in a cylinder holding from 1 to 1·5 litre, and shaken with a solution of barium hydrate, to rid it entirely of its carbonic acid. The cylinder was now placed on a stand, over which was disposed a glass receiver full of water, communicating by india-rubber tubing with the lower end of the cylinder. The india-rubber tube was carefully filled with water, so as to let no air into the cylinder, and then the cylinder was placed in communication with the eudiometer. The next stage was to wash out the passage in the stop-cock with the air to be analysed; this was done by connecting by india-rubber tubing the three-way cock with the cylinder, and some 200 or 300 c.c. of air were driven through it from the cylinder by the pressure of the water in the receiver; the iron tube was now stoppered on the opposite side by a short rubber-tube and pinch-cock. The mercury in the eudiometer was next let out at the bottom until a sufficient diminution of pressure had been obtained to aspire the requisite volume of air from the cylinder. This air was admitted from the cylinder while under pressure, and taken into the eudiometer by aspiration, so that the effect produced was that of a piston driving the hydrogen before it, and giving it no time to diffuse out of the instrument. The height of the mercury was now adjusted in both limbs by pouring in mercury, or letting it out at the bottom, and finally the reading was taken and recorded. The air and hydrogen were now thoroughly mixed by fitting an india-rubber syringe to the open end of the eudiometer and pressing it with the hand; a

succession of pressures soon effected a perfect mixture. The mixture was exploded as usual with a battery, when but little commotion was produced. Then mercury was added through the open limb, and the level adjusted in the two limbs; a very short time sufficed to ensure no further contraction or dilatation, and then the height of the mercury was read off. In the calculation of the analyses a slight correction was introduced, from the increased temperature of the water in the jacket owing to the flash.

This method proved extremely convenient and reliable. An experiment could be commenced in the afternoon, say 4 o'clock; the combination with barium hydrate for the determination of CO_2 was effected immediately after the air had been expired, and the turbid fluid left till the following morning for titration. Next, air was drawn into another cylinder by displacement with water, shaken with a solution of barium hydrate for about 12 minutes, and then the cylinder was placed on the stand for the determination of the oxygen in the air it contained. Fresh hydrogen was prepared for each experiment, and, as stated before, it was, in nearly every case, tested with atmospheric air before being used.

The calculations of the analyses were made as follows: the volume of the air expired, amounting to about 36 litres, was reduced to the dry state, 0° C., and 760 mm. pressure. This was done very rapidly by means of the Table I have constructed for the purpose.* Then the volume of CO_2 present was easily obtained from the weight of this gas found in the analysis. Next, the volume of CO_2 was subtracted from the volume of air expired, and the oxygen calculated on the reduced volume. With these data concerning the volume of air expired, a Table was constructed, of which the following is an illustration:—

Table Illustrating the Results of an Experiment.

Volume air inspired.			Volume air expired.		
33259		100	33008		100
CO_2	30 c.c.	0·09	CO_2	1885 c.c.	5·71
O	6961 ,,	20·93	O	4855 ,,	14·71
N	26268 ,,	78·98	N	26268 ,,	79·58
33259		100	33008		100

Volume oxygen consumed	2106	c.c.
Volume carbonic acid produced	1855	,,
Ratio of oxygen consumed to CO_2 produced	0·881	
Volume oxygen absorbed	251	c.c.

* 'Phil. Trans.,' 1890.

Volume oxygen absorbed per minute.................	39·6	c.c.
Volume oxygen absorbed per 100 air inspired.........	0·75	„
Volume oxygen absorbed per 100 O inspired	3·61	„
Weight oxygen consumed per hour..................	28·60	grams.
Weight oxygen consumed per kilo. weight of body	0·416	„
Weight CO_2 expired per minute.....................	0·577	„

The volume of air *inspired* was calculated from the *nitrogen* found in the air expired, and this is one of the main features of the present paper. A number of experiments were undertaken to try if any accurate determination could be made of the air inspired and expired by filling a counterpoise bell-jar with a measured volume of air, inspiring this air through the nose and expiring it into an empty bell-jar through the mouth. The plan, however, did not prove successful, and it was found impossible by this means to determine with a sufficient degree of accuracy the differences of volumes between the air inspired and expired. It then occurred to me that the volume of nitrogen found in air expired might afford a means of determining the volume of air inspired. According to one of the results obtained from Regnault and Reiset's experiments there is, under ordinary circumstances, a trifling amount of nitrogen exhaled from the blood in the process of respiration. The volume of this gas is, however, so small that its mean proportion in dogs fed with meat was only found to amount to the 0·0066 part of the oxygen consumed. This means from 11 to 13 c.c. in 1800 or 2000 c.c. of oxygen consumed and in about 33,000 c.c. of air breathed, a figure so low that, practically, the nitrogen exhaled may be ignored in the calculation of the analyses. I have entered the correction in some of the calculations, and it alters the volume of oxygen consumed by about 0·6 per cent., and that of the oxygen absorbed by 1 or 1·5 per cent. These corrections are so small that I have not thought it worth while to make them, and the nitrogen has been taken as the same in the air expired and inspired.

It was now easy to calculate the volume of air inspired. This volume consisted of the atmospheric carbonic acid, oxygen, which was taken in the proportion of 20·93 per cent., and nitrogen. The atmospheric carbonic acid was determined in every experiment by Pettenkofer's method; it ranged from 5 to 10 parts in 10,000. In the course of last April an additional window was made in my laboratory, which allowed of improved ventilation.

Having prepared a table of the constituents per cent. of the air inspired, the *volume* of air inspired was calculated as follows:—The nitrogen (per cent.) in the air *inspired* is to 100, so is the nitrogen in the air *expired* to the volume of air *inspired*. The volume of air inspired is thus obtained with much greater accuracy than by any experimental method, as the nitrogen must invariably exhibit the

same proportion whatever the volume of air expired. By this means the results obtained for the volumes of oxygen *consumed* and *absorbed*, which are the main objects of the present enquiry, are thoroughly reliable.

The experiments are made on two different persons, and show that not only the carbonic acid expired within a given time but also the oxygen consumed varies according to individuals. The subjects of these experiments are well suited to show "extremes" as to the function of respiration, one of them being 63 years of age and the other 21, both in perfect health.

Twelve experiments were made in both cases, six while under the influence of food and six while fasting. No experiments were made under extreme fasting.*

On considering the Tables, the composition per cent. of the air expired is observed to alter but little. In my case the CO_2 varies from 4·53 to 5·14.

The proportion of oxygen was very constant, ranging also with me from 15·30 to 16·0.

The volumes of oxygen consumed represented the volumes of oxygen the body took up, on one hand for the combustion and elimination of carbon in the form of carbonic acid, on the other, for the probable elimination of tissues in the form of crystalloid compounds. The relations between the oxygen consumed and the carbonic acid produced varied in my case between 0·816 and 0·912 with a mean of 0·863.

The proportion of the oxygen consumed which is *absorbed* is easily found by subtracting the volume of CO_2 produced from the total volume of oxygen consumed. This volume has been expressed *as absorbed per minute*, a result obtained by dividing the figure found by the number of minutes and seconds the experiment lasted. The volumes absorbed per minute varied in my case from 21·3 to 42·8 c.c., with a mean of 33·0 c.c.; this was equal to 2·83 grams of oxygen absorbed per hour. It may be concluded that this absorption of oxygen is an important factor towards the phenomena of nutrition.

The proportion of oxygen *absorbed* in my case for 100 parts of *air* inspired exhibits a mean of 0·74 part, and varies from 0·44 to 1·03. This does not agree with the volume of oxygen usually considered as absorbed, amounting to about 2 per cent. The corresponding proportion for the experiments on Mr. Russell will be found nearly exactly that obtained for myself, and I must conclude that 0·74 per cent., or a closely approximating figure, shows the proportion of the air inspired (in the form of oxygen) which remains in the blood, and consequently does not reappear in the corresponding air

* See Tables accompanying this paper.

expired. The mean proportion of oxygen absorbed in the *oxygen* inspired amounted to 3·57 per cent.

The weight of oxygen consumed per hour varies according to the person under experiment, and also in relation to the lapse of time after the ingestion of food. It ranged in my case from 19·75 grams to 22·02; and per kilo. weight of my body, from 0·338 to 0·376 gram. This is a much smaller proportion than that given for animals either by Regnault and Reiset or Chapman and Brubacker.

Influence of Food.—Food, in my case, at a mean time of 2 hours and 16 minutes after its ingestion, exerted apparently no effect on the proportions of CO_2, O, and N expired, as they were nearly exactly the same in both cases.

The ratio between the oxygen consumed and CO_2 produced exhibited, in my case, a decided tendency to fall while under the fasting state, the figures obtained being 0·870 while under the influence of food, and 0·850 while fasting.

The volumes of oxygen absorbed were much the same in both cases, although exhibiting a tendency to rise while fasting.

The differences between the proportions of oxygen absorbed in 100 volumes of air, or 100 of oxygen, under the influence of digestion or fasting are inappreciable.

There is a decided excess in the weight of oxygen consumed under the influence of food over that consumed fasting; the figures being 21·37 grams after food, and 20·26 grams fasting.

The weight of CO_2 expired per minute varies as usual according to the influence of food, and calls for no comment.

Mr. Russell also submitted to twelve experiments, six made at a mean time of two hours after a meal, and six while fasting, or at a mean time of four hours and twenty-three minutes after food. The proportions per cent. of CO_2, O, and N expired are much alike in every experiment, varying as follows:—CO_2, 5·38 to 5·96; O, 14·39 to 15·26; N, 79·36 to 79·92. The ratio of oxygen consumed to CO_2 produced varies from 0·818 to 0·923, with a mean of 0·878. This closely approximates the corresponding means obtained in my own case, amounting to 0·863, which, however, is slightly lower. The next figures in the table, showing the proportion of oxygen consumed on 100 of air and 100 of O breathed, give means very nearly the same as when I submitted to experiment.

The weights of oxygen consumed per hour, 25·98 grams, and per kilo. of body weight per hour, 0·380, are decidedly higher than in my case. Mr. Russell also expired a greater weight of CO_2 per minute than I did, showing greater activity in the process of nutrition—a phenomenon probably due to youth.

The influence of *digestion* and *fasting* shows no alteration in the proportions of CO_2, O, and N expired. The difference in the ratio

between O consumed and CO_2 produced is barely perceptible, although exhibiting a slight tendency to fall while fasting. The proportions of oxygen absorbed in 100 of air and oxygen inspired are much the same under the influence of food and fasting.

The main effect produced on Mr. Russell by the ingestion of food and fasting is to be found in the weight of oxygen consumed per hour, which falls from 28·66 grams under the influence of food to 23·30 when fasting, and per kilo. weight from 0·417 gram to 0·330 gram. There is also, when fasting, a considerable reduction of weight of the CO_2 expired per minute (0·578 gram to 0·468 gram).

The results obtained from the present investigation of the interchange of gases in the respiratory process of man may be summed up as follows:—

1. The percentage of CO_2, O, and N in the air expired alters according to the person under experiment, but in every case the proportions of each gas vary but slightly up to a period of about four hours and a half after the mid-day meal, a result I had formerly obtained for CO_2.
2. The ratio between the oxygen consumed and the carbonic acid produced exhibited a mean of 0·871 for two persons and twenty-four experiments. This is nearly the same figure as that obtained by Messrs. Jolyet, Bergonié, and Sigalas—0·868, and a marked approximation to 0·90, the corresponding ratio given for rabbits by Messrs. Chapman and Brubacker.
3. The mean volume of oxygen *absorbed* per minute was very nearly the same for the two persons, and amounted to a total mean of 34·3 c.c. on twenty-four experiments. This would be equal to 2·94 grams of oxygen absorbed per hour.
4. The mean volume of *oxygen* absorbed in relation to *the air inspired* proved nearly the same in both persons submitted to experiment, and amounted to 0·75 per cent. A similar remark applies to the proportions of oxygen absorbed to the *oxygen inhaled;* the figures are 36·9 in one case, and 3·55 in the other, with a mean of 3·63.
5. The mean weight of oxygen consumed per hour varied with each person submitted to experiment, amounting to 20·81 grams in the older and 26·09 in the younger man. The corresponding figures per kilo. of body weight were 0·355 gram and 0·380 gram.
6. The weight of carbonic acid expired per minute is notably higher in the younger man, and corresponds approximately to proportionally increased amount of oxygen consumed.

The elaborate investigation of Messrs. Hanriot and Richet calls for a few remarks.

The mean ventilation of the lungs, by which expression I conclude Messrs. Hanriot and Richet mean the sum of the air inspired and expired, amounts, according to these authors, to 10 litres of air per kilo. weight of the body per hour. This result agrees, within certain limits, with those I have obtained. The sum of the air inspired and expired in each experiment gives, in my case, a maximum of 9·94 litres per kilo. weight per hour, and a minimum of 8·33 litres, with a mean of 9·12 litres, which is near to Messrs. Hanriot and Richet's figure of 10 litres. Mr. Russell's mean pulmonary ventilation is decidedly less than mine, and lower than the figure obtained by the French authors, amounting to a maximum of 9·51 litres and a minimum of 6·87 litres, the mean being 8·13 litres. It is therefore obvious that the pulmonary ventilation varies per kilo. weight of body, according to different people. Messrs. Hanriot and Richet apparently experimented only on a single person.

The volume of carbonic acid in 100 of expired air appears decidedly low in Messrs. Hanriot and Richet's experiments, amounting to a mean of 3·30. In the experiments which form the subject of the present paper, the corresponding proportion varied, for myself between 4·53 and 5·14, and for Mr. Russell between 5·38 and 5·90. These proportions, to which I have drawn attention in former communications, vary not only with different individuals, but with the same person under different circumstances. The relation between the oxygen consumed and CO_2 produced is decidedly smaller in Messrs. Hanriot and Richet's experiments than in my own; those gentlemen find the mean relation in question to be 0·78, while the mean from my experiments on two different persons yield 0·871.

The second part of the present communication deals with the respiration of air containing from 2·5 to 4 per cent. of carbonic acid. The mixture was made by introducing carbonic acid, prepared from marble and hydrochloric acid, into a certain volume of air drawn into one of the bell-jars. The mixture was first of all analysed for the determination of the CO_2 it contained, and then it was inspired through the nose, by means of a well-fitting nose-piece, and expired into the other bell-jar through the mouth. The first five or six inspirations were used for rinsing out the lungs and the bell-jar, and were driven out of the second bell-jar through a T-piece, while the person under experiment was expiring into the open air; this was easily effected by means of the three-way stop-cock; then the stop-cock was again turned, and the expired air collected in the bell-jar while the time was taken. The effects produced were a sensation of want of air and a considerable increase in the volume of air breathed per minute. The air expired, during a period of from 2 to 4 minutes, was collected for experiment; but the breathing of the air and CO_2 was carried on altogether for 4 or 5 minutes. No lasting ill effects

were produced on either of us. I submitted to three experiments and Mr. Russell to two.

These experiments (with one exception) were undertaken at the same time as others made with fresh air, though about an hour later, and references are entered in the following table in order that the corresponding experiments may be compared with each other.

Air Breathed containing an excess of Carbonic Acid.

Dr. Marcet under experiment.

	Experiment I.	Experiment II.		Experiment III.	
	2·53 per cent. CO_2 inspired. Time after food, $2^h\ 45^m$. Lab. temp., 10°·5. Bar., 758·7.	3·54 per cent. CO_2 inspired. Time after food, $3^h\ 25^m$. Lab. temp., 10°·4. Bar., 756·4.		4·06 per cent. CO_2 inspired. Time after food, $2^h\ 30^m$. Lab. temp., 12°·9. Bar., 762·7.	
	On 100 expired.	On 100 expired.		On 100 expired.	
CO_2	5·88	6·25	Compares with Experiment No. 5 on ordinary respiration (same sitting).	6·29	Compares with Experiment No. 6 on ordinary respiration (same sitting).
O	16·14	16·21		16·78	
N	77·98	77·56		76·93	
O consumed ..	858	1085		831	
CO_2 produced.	633	668		505	
Relation......	0·738	0·616		0·608	
O absorbed per minute......	71	112		127	
O absorbed on 100 air inspired	1·16	1·63		1·39	
O absorbed on 100 O inspired	5·71	8·08		6·90	
Weight O consumed per hour	23·31	25·11		27·84	
Weight O per hour per kilo.	0·398	0·429		0·476	
Weight CO_2 expired per minute......	0·393	0·354		0·388	

Mr. Russell under experiment.

	Experiment I.		Experiment II.	
CO_2 in air breathed	3·79 per cent.		3·91 per cent.	
Time after food	3 hours	Compares with Experiment No. 4 on ordinary respiration (same sitting).	3 hours	Compares with Experiment No. 6 on ordinary respiration (same sitting).
Laboratory temperature	10°·9		16·7	
Barometer	759·5		764·0	
On 100 parts air expired.				
CO_2	6·62		6·54	
O	15·90		15·80	
N	77·48		77·66	
O consumed	1073		1079	
CO_2 formed	642		579	
Relation	0·598		0·537	
O absorbed per minute	141 c.c.		170 c.c.	
O absorbed per 100 air expired	1·82		2·15	
O absorbed per 100 O expired	9·03		10·70	
Weight O consumed per hour	30·26		31·64	
Weight O consumed per kilo	0·440		0·460	
CO_2 expired per minute	0·415		0·389	

On a consideration of the foregoing tables it will be seen that the CO_2 expired (per cent. of air expired) does not represent the CO_2 exhaled from the blood, but the figure is much higher, as it includes the CO_2 inspired, which is expired together with the proportion exhaled. The volume of CO_2 actually exhaled from the blood can be calculated by subtracting the proportion of CO_2 in the air *inspired* from the corresponding proportion of CO_2 in the air *expired*. The volumes of CO_3 actually found in the expired air have not been entered in the following table (p. 71), but the figures represent these volumes less the corresponding proportions of CO_2 in the air inspired, and they show that the CO_2 actually exhaled from the blood is very much less than in ordinary respiration.

It will therefore be observed that nearly half the CO_2 which would have been expired in natural breathing has been retained in the body. Of course this is assuming that no CO_2 has been absorbed directly at the lungs. Hence there must be a very great accumulation of CO_2 in the blood when air containing CO_2 is inspired.

It follows from this inquiry on the respiration of air containing from 2·5 to 4 per cent. of CO_2—

1st. That the proportion of oxygen in 100 of air expired exhibits a slight increase beyond its proportion in ordinary breathing.

2nd. That the relation between the oxygen consumed and CO_2 produced is very much smaller than in ordinary respiration, amounting to a mean of 0·654 for myself and 0·567 for Mr. Russell, against a total mean of 0·871 for both of us in ordinary breathing.

Dr. Marcet.

Percentage CO_2 expired in ordinary breathing.	Percentage CO_2 in air inspired.	Percentage CO_2 exhaled from blood when breathing air and CO_2.
1. ...... 5·12	3·54	2·66
2 ...... 5·12*	2·53	3·32
3. ...... 5·14	4·06	2·17
Means ... 5·13	3·38	2·72
	Mr. Russell.	
1. ...... 5·69	3·79	2·76
2. ...... 5·51	3·91	2·55
Means ... 5·60	3·91	2·65

3rd. That the volume of oxygen absorbed per minute is greatly increased, my own mean amounting to 103 c.c., and Mr. Russell's to 155 c.c., instead of 32·2 in my case and 37·5 in the other.

4th. That the proportions per cent. of oxygen absorbed in the air inspired are increased in both cases to a mean of 1·39 against 0·66, and to a mean of 1·98 against 0·75 in ordinary breathing. A corresponding increase is observed in the proportion of oxygen absorbed to the oxygen inspired.

5th. That the weight of oxygen consumed by the body per hour is considerably increased, amounting to a mean in my case of 25·42 grams, against 21·37 grams, and with Mr. Russell of 30·95 grams against 28·66 in ordinary breathing.

6th. That the weight of carbonic acid expired per minute is considerably reduced, amounting in my case to a mean of 0·378 instead of 0·430, and with Mr. Russell to a mean of 0·402 instead of 0·578 expired in normal respiration.

These experiments, although but few in number, suffice to show that when air is breathed containing from 2·5 to 4 per cent. of CO_2 the amount of oxygen consumed is much greater than in ordinary breathing, while the carbonic acid expired is very much less. There must consequently remain in the blood a considerable amount of oxygen to be transformed into an excess of CO_2 besides the proportion required towards the other functions of the body.

* The analyses following fig. 2 do not really correspond, but are made under similar circumstances of food, temperature, &c., and are therefore made to compare with each other in this table.

Experiments on Ordinary Respiration showing the Composition of the Air Expired and the Interchange of Gases.

Experiments made under the Influence of Food.

(Dr. Marcet under experiment.)

	Exp. 1.	Exp. 2.	Exp. 3.	Exp. 4.	Exp. 5.	Exp. 6.	Means after food.
Time of food	2 hours after lunch	2 hours after lunch	3 hours after lunch	$2\frac{1}{2}$ hours after lunch	2 hours 25 mins. after lunch	1 hour 40 mins. after lunch.	2 hours 16 mins. after lunch.
Laboratory temperature	18·0	17·4	16·2	15·5	10·4	12·0	14·9
Barometer	766·0	757·9	752·75	757·0	756·4	762·7	758·8
on 100 expired.		on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.
CO_2	4·69	4·86	4·70	4·86	5·12	5·14	4·89
O	16·01	15·51	15·69	15·57	15·43	15·44	15·61
N	79·30	79·63	79·61	79·57	79·45	79·42	79·50
O consumed	1696	1858	1749	1843	3305	1766	—
CO_2 produced	1547	1593	1487	1579	2954	1593	—
Relation..............................	0·912	0·857	0·850	0·857	0·898	0·902	0·879
O absorbed	149	265	262	264	351	173	—
O absorbed per minute	21·3	34·9	36·7	36·7	27	24·8	30·2
O absorbed on 100 air expired	0·44	0·79	0·80	0·79	0·59	0·55	0·66
O absorbed on 100 O inspired	2·09	3·78	3·84	3·75	2·83	2·61	3·15
Weight O consumed per hour	20·84	20 58	21·09	22·02	21·81	21·81	21·37
Weight O per hour per kilo....	0·356	0·352	0·360	0·376	0·374	0·373	0·361
Weight CO_2 expired per minute	0·436	0·404	0·411	0·432	0·448	0·451	0·430

Experiments made Fasting.

	Exp 7.	Exp. 8.	Exp. 9.	Exp. 10.	Exp. 11.	Exp. 12.	Means fasting.	Total means.
Time after food...	4 hrs. after breakfast	4 hours after breakfast	4 hours after breakfast	4 hours 18 mins. after breakfast	4 hours 20 mins. after breakfast	4½ hours after breakfast	4 hours 11 mins. after food.	3 hours 13 mins. after food.
Laboratory temperature	14·6	14·6	16·1	16·1	15·2	23·3	16·7	15·9
Barometer	748·6	748·6	761·5	751·8	761·9	763·0	755·9	757·3
	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.
CO_2	4·71	4·72	4·53	4·71	4·98	5·14	4·80	4·84 CO_2
O	15·71	15·46	16·07	15·54	15·33	15·27	15·56	15·51 O
N..................................	79·58	79·82	79·40	79·75	79·69	79·59	79·64	79·56 N
O consumed	1716	1818	1674	1821	1838	1774	—	—
CO_2 produced	1479	1484	1490	1494	1562	1533	—	—
Relation	0·862	0·816	0·890	0·820	0·850	0·864	0·850	0·864
O absorbed	237	334	184	327	276	242	—	—
O absorbed per minute	32·2	42·2	25·7	42·8	36·4	32·3	35·3	32·7
O absorbed on 100 air expired	0·74	1·03	0·54	1	0·86	0·79	0·83	0·74
O absorbed on 100 O inspired	3·52	4·94	2·60	4·79	4·12	3·77	3·96	3·55
Weight O consumed per hour	20·04	19·75	20·14	20·52	20·84	20·35	20·27	20·82
Weight O per hour per kilo....	0·342	0·338	0·344	0·351	0·356	0·348	0·346	0·355
Weight CO_2 expired per minute	0·396	0·369	0·411	0·386	0·406	0·403	0·395	0·412

Experiments on Ordinary Respiration showing the Composition of the Air expired and the Interchange of Gases.

Experiments made under the Influence of Food.

(Mr. Russell under experiment.)

	Exp. 1. P. 157.	Exp. 2.	Exp. 3.	Exp. 4.	Exp. 5.	Exp. 6.	Means after food.
Time after food ...	2 hours after lunch.	2 hours 15 mins. after lunch.	2 hours 15 mins. after lunch.	2 hours after breakfast.	1 hour 44 mins. after lunch.	2 hours after lunch.	2 hours 2 mins.
Laboratory temperature	15·5	16·1	15·0	10·9	12·0	16·7	14·4
Barometer........................	760·7	751·4	751·0	759·5	761·2	764·0	758·0
on 100 expired.		on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.
CO_2	5·52	5·67	5·71	5·69	5·90	5·51	5·67
O	14·56	14·93	14·71	14·95	14·42	14·94	14·75
N	79·92	79·40	79·58	79·36	79·68	79·55	79·58
O consumed	2205	2094	2106	4069	4442	2047	—
CO_2 produced	1804	1909	1855	3757	3851	1810	—
Relation	0·818	0·911	0·881	0·923	0·867	0·884	0·881
O absorbed	401	185	251	312	591	237	—
O absorbed per minute	62·0	29·6	39·6	25·3	45·0	37·3	37·5
O absorbed on 100 expired ...	1·19	0·540	0·755	0·464	0·884	0·706	0·75
O absorbed on 100 O inspired	5·68	2·57	3·61	2·22	4·22	3·37	3·61
Weight O consumed per hour	29·33	28·82	28·6	28·42	29·06	27·73	28·66
Weight O per hour per kilo....	0·427	0·419	0·416	0·414	0·423	0·403	0·417
Weight CO_2 expired per minute	0·550	0·602	0·577	0·601	0·577	0·562	0·578

Experiments made Fasting.

Exp. 7. P. 39.		Exp. 8.	Exp. 9.	Exp. 10.	Exp. 11.	Exp. 12.	Means fasting.	Total means.
Time after food, 4 hours 35 mins. after breakfast.		4 hours 5 mins. after lunch.	4 hours 25 mins. after breakfast.	4 hours 15 mins. after breakfast.	4 hours 35 mins. after breakfast.	4 hours 45 mins. after breakfast.	4 hours 23 mins. after food.	3 hours 12 mins. after food.
Laboratory temperature	15·5	16·7	15·3	18·4	16·0	21·1	16·4	15·4
Barometer	764·6	764·0	765·5	749·5	748·2	765·5	758·4	758·2
on 100 expired.		on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.	on 100 expired.
CO_2	5·52	5·38	5·50	5·8	5·78	5·84	5·64	5·63 CO_2
O	14·68	15·26	14·84	14·68	14·39	14·53	14·73	14·76 O
N	79·80	79·36	79·66	79·52	79·83	79·63	79·63	79·60 N
O consumed	2112	1887	1960	2066	2076	2062	—	—
CO_2 produced	1782	1733	1698	1858	1763	1816	—	—
Relation	0·844	0·918	0·866	0·899	0·849	0·881	0·876	0·878
O absorbed	330	154	262	208	313	246	—	—
O absorbed per minute	41·68	23·45	36·4	27·61	40·3	30·69	33·35	25·42
O absorbed on 100 expired ...	0·998	0·469	0·831	0·639	1·008	0·777	0·79	0·77
O absorbed on 100 O inspired	4·77	2·24	3·97	3·05	4·82	3·71	3·76	3·63
Weight O consumed per hour	22·95	24·72	23·41	23·59	22 99	22·12	23·30	25·98
Weight O per hour per kilo...	0·334	0·360	0·341	0·343	0·335	0·322	0·330	0·373
Weight CO_2 expired per minute	0·446	0·520	0·465	0·486	0·417	0·446	0·468	0·523